

EQUINOX

A SENSE OF DISASTER

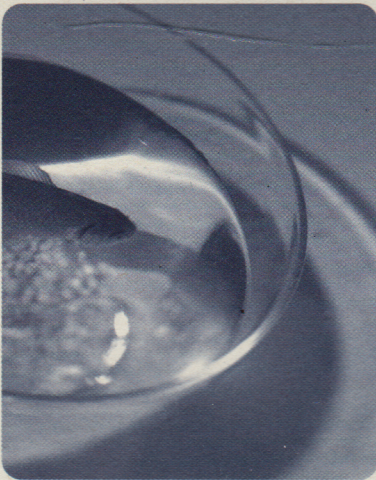
Earthquakes and earthquake prediction



EQUINOX

A SENSE OF DISASTER

by Chris Cooper



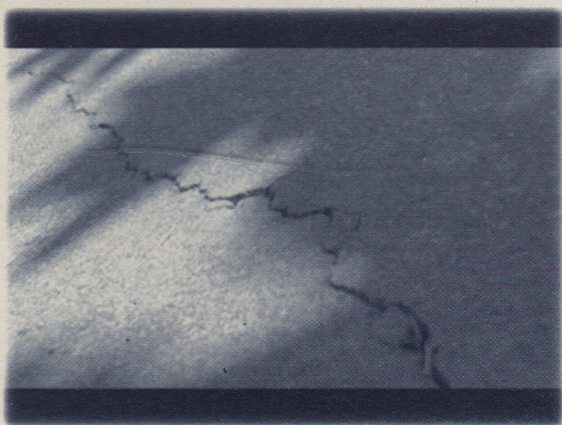
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AT 5.12AM on 18 April 1906, the ground in the part of California lying to the west of the San Andreas fault shifted in relation to the ground lying to the east. Deep below the surface, the movement measured as much as 8.5 metres (28 feet). At the surface, the maximum shift was 6 metres (20 feet). This was enough to create an earthquake that in less than two minutes levelled the city of San Francisco.



The scene on the following day was described for *Collier's* magazine by Jack London, a 30-year-old writer who had recently made his name with his novel *Call of the Wild*:

'Not in history has a modern imperial city been so completely destroyed. San Francisco is gone. Nothing remains of it but memories and a fringe of dwelling-houses on its outskirts. Its industrial section is wiped out. Its business section is wiped out. Its social and residential section is wiped out. The factories and warehouses, the great stores and newspaper buildings, the hotels and palaces of the nabobs, are all gone.'

Those who had avoided being crushed by falling buildings were still not safe. They faced the hazard of fire:

'Within an hour after the earthquake shock the smoke of San Francisco's burning was a lurid tower visible a hundred miles away. And for three days and nights this lurid tower swayed in the sky, reddening the sun, darkening the day, and filling the land with smoke.

'There was no opposing the flames. There was no organization, no communication. All the cunning adjustments of a twentieth century city had been smashed by the earthquake. The streets were humped into ridges and depressions, and piled with the debris of fallen walls.'



4

The official number of deaths following the earthquake and fire was 700, but the true number probably amounted to several thousand.

San Francisco had often felt the earth shake before. In *Roughing It*, Mark Twain describes an earthquake he experienced in 1865:

'As I turned the corner, around a frame house, there was a great rattle and jar, and it occurred to me that here was an item! – no doubt a fight in that house. Before I could turn and seek the door, there came a terrific shock; the ground seemed to roll under me in waves, interrupted by a violent joggling up and down, and there was a heavy grinding noise as of brick houses rubbing together. I fell up against the frame house and hurt my elbow. I knew what it was now ... a third and still severer shock came, and as I reeled about on the pavement trying to keep my footing, I saw a sight! The entire front of a tall four-storey brick building on Third Street sprung outward like a door and fell sprawling across the street, raising a great dust-like volume of smoke!'



Precarious position: the citizens of San Francisco have experienced several destructive earthquakes, rebuilding the city after each one

But despite such experiences, after each earthquake the people of San Francisco returned and built a city more splendid than the one that had been destroyed. A city's economic and social edifices are more resilient than its buildings, and earthquakes cannot destroy the geographical advantages that lead to the development of cities in the first place. Besides, generally much of a city's infrastructure survives even the worst shocks.

However, Californians now fear 'the Big One', an earthquake anticipated because many earth scientists have

warned that strain is building up in the San Andreas fault. In addition, a previously unknown and potentially disastrous fault has recently been discovered running beneath the centre of Los Angeles. Christened the Puente Hills fault, its shallowest point lies directly below the stadium of the Dodgers baseball team.

But neither Californians nor any other inhabitants of great cities in earthquake regions are likely to abandon their homes and livelihoods because of an indefinite threat. Only one thing could make them move: a credible prediction of when and where an earthquake will strike.

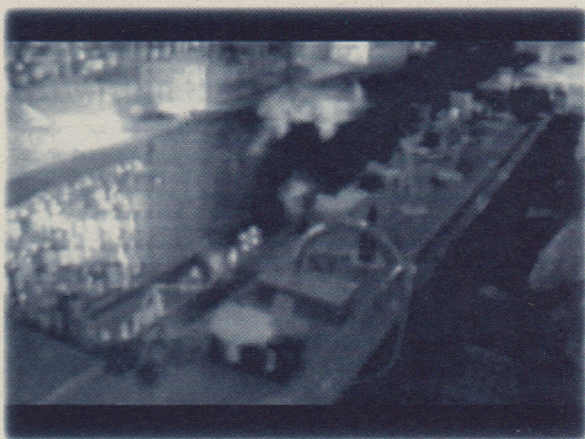
This booklet looks at the science of earthquakes, at some of the current methods of predicting them – scientific and otherwise – and at the prospects for prediction in the future.



THE DISASTER that struck San Francisco in 1906 was responsible for a milestone in the understanding of earthquakes. Previously the cause of earthquakes had been widely attributed to underground explosions. But when a geologist, Harry Fielding Reid, studied the San Francisco quake, he found that disturbances along the San Andreas fault extended for no less than 470 kilometres (290 miles). The scale of the disruption showed that an earthquake could be caused not by local disturbances but by distant forces.

Reid proposed a new theory, one that in its essentials is held today. He built on an insight of the American geologist Grove Karl Gilbert, whose study of the 1872 earthquake in Owens Valley, California, convinced him that the movement along a fault so often seen in an earthquake was not an *effect* of a tremor, but its *cause*. Reid suggested that the San Francisco earthquake was the result of huge forces in the earth's

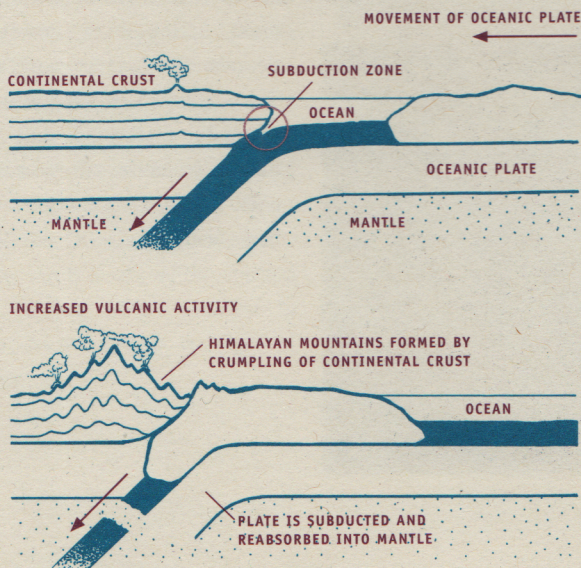
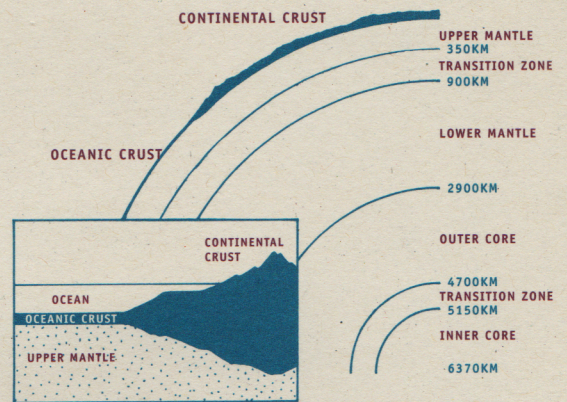
crust acting over immensely long periods. The land on each side of the San Andreas fault had been pushed in opposite directions, but had been unable to move. Stress had built up until finally the cohesion of the crust had given way.

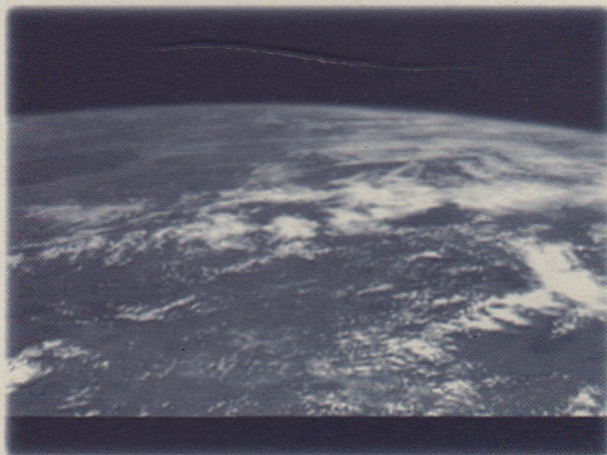


EARTHQUAKES AND PLATE TECTONICS

The reality of huge forces driving movements in the surface of the earth was undeniable by that time: they were evident in the uplifting and crumpling of strata in cliffs and eroded hillsides, for instance, and in the tearing apart of the ground in rift valleys. But the causes of these forces began to be understood only in the 1960s, when the theory of plate tectonics became established. According to this theory, the surface of the earth is continuously in motion. Continents are driven across the globe and against each other, completely remaking the face of the planet on a timescale of hundreds of millions of years.

The driving force is heat from the earth's molten core, which sets up currents in the semi-fluid layers of the mantle, lying outside the core. Floating on these currents is a crust of various kinds of lighter rock, comprising the continents and the ocean floors. The crust is divided into six large and at least 18 smaller sheets, called plates.





The earth's surface is divided into plates,
which are constantly in motion

At the trailing edge of a plate, new crustal material is formed where underlying currents in the upper mantle rise and diverge and the material solidifies. At its leading edge, a plate is pushed against an adjacent plate, either being forced up over it or down into the upper mantle, where the crustal material melts and is reabsorbed. The pressure of colliding plates causes crustal material to pile up, forming mountain ranges.

Most earthquakes occur where plates collide or grind past each other. The rock masses and overlying crust of adjacent plates cannot move

against each other freely, and stresses build up over a long period, until finally the crustal material slips suddenly. This slippage is an earthquake.

Earthquakes occur to a lesser extent where plates pull apart, because stresses build up in the crustal material formed between them. A few earthquakes also originate from stresses within plates.

Earthquake zones are often associated with volcanic activity, both where plates collide (as a result of frictional heat) and where they move apart (because heat rises from the depths in these areas). For

instance, there is a ridge of undersea volcanoes and an associated earthquake zone running down the middle of the North and South Atlantic Oceans, where plates carrying the Americas on the one hand and Eurasia and Africa on the other are moving apart. The Pacific plate, moving generally westward, creates the 'ring of fire' – the great zone of earthquake and volcanic activity that encircles the Pacific Ocean. The San Andreas fault is the line along which the Pacific plate slides against the North American plate, at a rate of about 1.5cm (half an inch) per year.



EARTHQUAKES OF THE PAST

The following are just a few earthquakes notable for the destruction they caused or for the energy they released (see 'The Scales of Destruction' on page 12). Numbers of deaths are not precise, especially for earlier earthquakes.

DATE	LOCATION	MAGNITUDE	DEATHS
AD 526	Antioch, Syria (now Turkey)	unknown	250,000
1556	Northern China	unknown	830,000
1703	Tokyo, Japan	unknown	200,000
1755	Lisbon, Portugal	unknown	60,000
1812	Caracas, Venezuela	unknown	12,000
1896	Sanriku, Japan	unknown	20,000
April 1905	Kangra, India	8.3	375,000
April 1906	San Francisco, USA	7.7	700
December 1908	Messina, Sicily	7.5	160,000
December 1920	Kansu, China	8.6	200,000
September 1923	Sagami Bay, Japan	8.3	150,000
August 1950	Assam, India	8.6	30,000
May 1960	Chile	9.5	2,000
March 1964	Alaska	9.2	114
July 1976	Tangshan, China	7.8	250,000
September 1993	India	6.4	13,000
January 1994	Los Angeles, USA	6.7	57
January 1995	Kobe, Japan	6.9	5,500

ENERGY, DEPTH AND DAMAGE

An earth tremor originates at an underground location called the focus or hypocentre. This is described as shallow if it is less than 70 kilometres (43 miles) below the surface; intermediate if it is 70–300 kilometres (43–186 miles) below the surface; and deep if it is more than 300 kilometres (186 miles) below the surface. The deepest earthquake hypocentres recorded lie 700–750 kilometres (435–465 miles) down. At greater depths, temperatures are too high and the rock too fluid for long-term stresses to build up.

The energy released by an earthquake is only indirectly related to surface damage, which is magnified when the hypocentre is shallow or if

the surface crust consists of loosely compacted sedimentary rock as opposed to bedrock. For instance, in 1985 a large earthquake caused a catastrophe in Mexico City, even though it was centred 300 kilometres away.

The scale of the destruction was largely due to the fact that parts of the city were built on soil filling a rock basin. Over 8,000 people died.

The number of casualties in populated areas also depends on standards of construction and design and on when the earthquake strikes. Casualties were reduced

in the 1989 Loma Prieta earthquake in California because traffic was light, despite the fact that it was rush hour – the citizens of San Francisco and Oakland were at the first match of the baseball World Series or watching the game on TV. Only 63 deaths are officially recorded. Well-designed and well-constructed buildings generally resisted the shock, but four elevated sections of road toppled.

The importance of building design and construction was also illustrated by the earthquake that struck the Japanese port city of Kobe on 17 January 1995. More than 5,500 people died, but structures built on deep pilings, including the world's longest suspension bridge, then under construction, were barely damaged.



The Loma Prieta quake toppled four elevated sections of road, but most well-built structures resisted the shock

THE SCALES OF DESTRUCTION

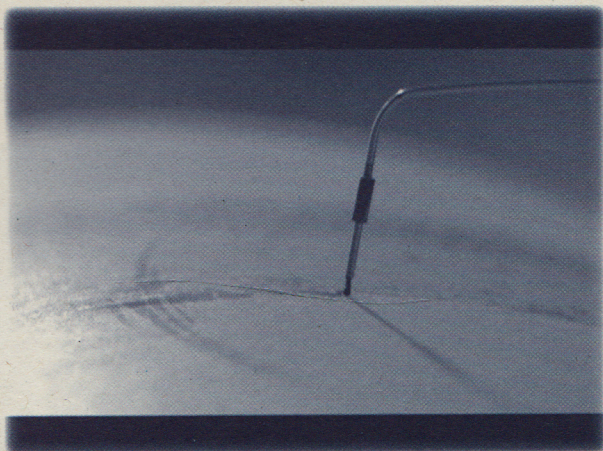
Two different scales are used to measure earthquakes. THE RICHTER SCALE was devised by the US seismologist Charles Francis Richter in 1935. It is a measure of the energy released in an earthquake, regardless of the damage caused. The energy is calculated from the size of the area affected and from the amount of horizontal and vertical surface displacement, as measured by seismographs (see page 15).

The Richter Scale resembles a steep curve in which each unit represents an approximately 31-fold increase in energy. This means that the difference in energy released

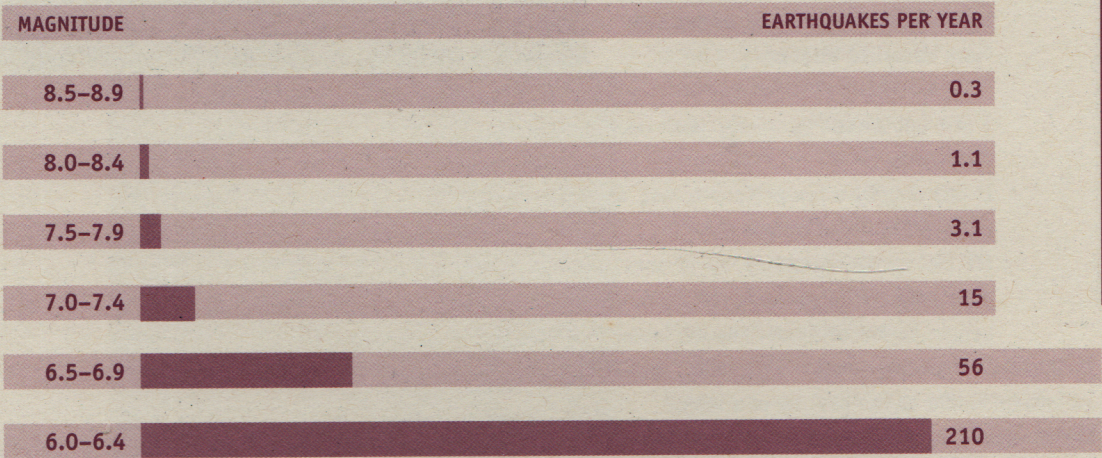
risks dramatically as you move up the scale.

The seismic energy from a magnitude-6 quake, for example, is the equivalent of a thousand tonnes of TNT or a 1-kilotonne hydrogen bomb. Magnitude 7 represents about 32 kilotonnes and magnitude 8 nearly 1,000 kilotonnes. The largest earthquake ever recorded, the 9.5 Chilean quake of 1960, released seismic energy equivalent to about 160,000 kilotonnes.

Disturbances below about 2.5 on the Richter scale are generally imperceptible to humans. The thousands of shocks above 4.5 that occur each year around the world can be recorded by sensitive seismographs. Tremors above 6.0 are described as major earthquakes and those above 8.0 as great earthquakes.



The average annual number of major and great earthquakes, derived from records covering a 47-year period, is shown in the chart below.



SOURCE: US GEOLOGICAL SURVEY

Whereas the Richter scale measures energy, THE MERCALLI SCALE, introduced in 1900 by the Italian seismologist Giuseppe Mercalli, gives an indication of an earthquake's intensity at a particular point on the earth's surface. Values on this scale, therefore, vary from place to place.

THE MODIFIED MERCALLI (MM) scale was developed in 1931 by the American seismologists Harry Wood and Frank Neumann. It consists of 12 levels of intensity, designated by Roman numerals and estimated from observed effects:



I Not felt except by a very few under special conditions.

II Felt only by a few persons at rest, especially on upper floors of buildings.

III Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognise the disturbance as an

earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a lorry.

IV Felt indoors by many, outdoors by a few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V Felt by nearly everyone. Many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

VI Felt by all. Many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.

VII Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken.

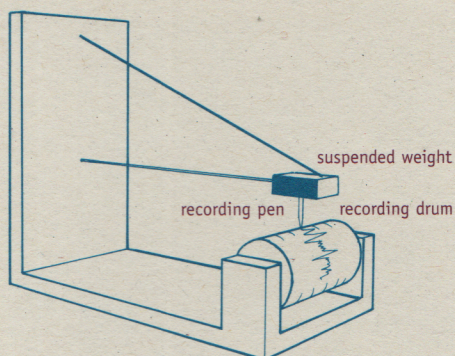
VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.

IX Damage considerable in specially designed structures. Well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.

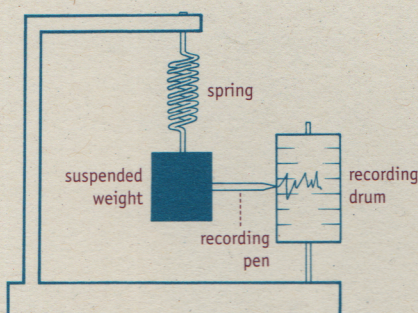
X Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations.

XI Few structures remain standing. Bridges destroyed.

XII Damage total. Lines of sight and levels are distorted. Objects thrown into the air.



Basic seismograph designs for measuring (top) horizontal and (below) vertical ground movements

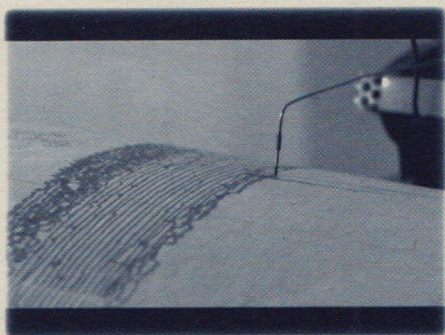


SEISMOGRAPHS

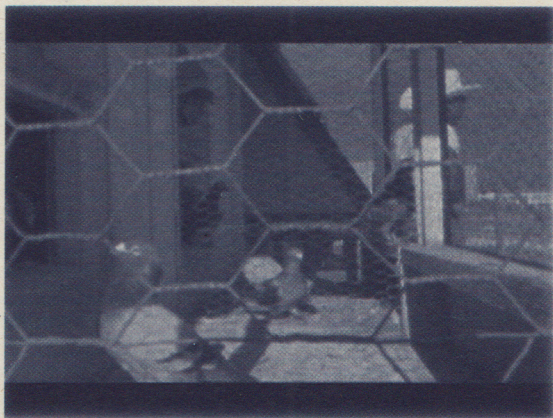
In a seismograph of classic design for recording horizontal ground movements, a pen is attached to a weight hanging on a wire. The pen draws a trace on graph paper wrapped around a rotating drum mounted beneath the pen. The drum is attached to a frame firmly fixed to the ground. During an earth tremor the drum moves, but the suspended weight does not, so the pen records the shift on the graph. Two such instruments, aligned north-south and east-west, can produce a complete record of horizontal earth movements.

Vertical movements are recorded by a pen attached to a weight hanging on a spring. The pen draws on a graph mounted alongside it. When the ground moves up and down, the drum moves with it, but the weight and pen remain stationary.

Modern seismographs also use weights hanging from wires or mounted on springs, but replace pen and paper with electromagnetic movement sensors. Their measurements are directly converted into electronic signals.







There have been many reports that animals are disturbed prior to earthquakes.

Nick Corini, for instance, says some of his female pigeons abandoned their eggs before the Loma Prieta quake.

GIVEN THE destructive power of earthquakes and the fact that earthquake zones include many densely populated areas, the potential importance of a reliable method of predicting shocks is obvious. However, earthquake prediction is a highly complex and controversial field.

Would-be predictors fall into two main groups: those who put their faith in everyday signs or omens and those who rely on scientific instruments to measure other phenomena. The latter often look down on the former but are in turn disparaged by many of their peers. Unlike hurricanes and tidal waves, earthquakes gestate invisibly, and no herald of their coming is generally accepted as valid and reliable in the scientific community.

There are many popular traditions about signs indicating a coming earthquake. It has been said that the weather changes, animals are disturbed or disappear and domestic appliances malfunction, for example. The logical explanation for many such occurrences is coincidence. But some signs involve phenomena of interest to earth scientists.

GROUNDWATER

One such phenomenon that interests scientists relates to observations of water from underground sources. The level of water in wells has been reported to rise and fall before earthquakes, and close monitoring of a particular geyser in Calistoga, northern California, seems to suggest that the pattern of its eruptions is affected by a developing shock.

Olga Kolbek has been watching the geyser on her land for 25 years. It is one of many in the United States that bear the name 'Old Faithful'. 'Old Faithful' geysers gush from the earth at regular intervals. Water flowing deep underground meets hot rock, becomes superheated and is forced upwards under its own pressure. As some of the water escapes, the underground pressure drops, the boiling point of the remaining water falls, the water turns into steam and the geyser explodes.

The geyser on Olga Kolbek's land erupts every 40 minutes – except, she says, before an earthquake. 'Back on 1 August 1975, I was sitting in the picnic area, and it didn't erupt for two and a half hours. That evening I found out we had an earthquake 100 miles north of here, at Orville, California – 5.9 on the Richter scale.'

Since 1980 a computer has tracked the geyser 24 hours a day. Before the Loma Prieta earthquake of 1989, the gap recorded between eruptions nearly doubled. Paul Silver, a geophysicist at the Carnegie Institution of Washington, believes that the geyser is registering the underground development of at least some of the earthquakes within a 250-kilometre (150-mile) range. Exactly why Old Faithful is

affected by earthquakes is not fully understood – but its record of constant monitoring provides data for any sceptic to see.

Increased radon levels in underground water are also considered by some scientists to foreshadow earthquakes. Radon is given off by underground rocks and is released more rapidly into groundwater when underground pressure increases. Chinese scientists appear to have made accurate predictions partly based on measuring radon levels in spring water (see 'The Chinese Experience', page 24). In Japan, Professor Hiroshi Wakita of Tokyo University studied spring water that had been bottled in Kobe just before the earthquake of 1995 and found many alterations in its composition – notably an increase in radon.

Olga Kolbek and the geyser on her land, whose regular pattern of eruption seems to be disturbed by coming quakes



ELECTRICAL CONNECTIONS

Unusual electrical effects might also have some connection with earthquakes – and might again provide some basis for particular beliefs and folk traditions associated with them.

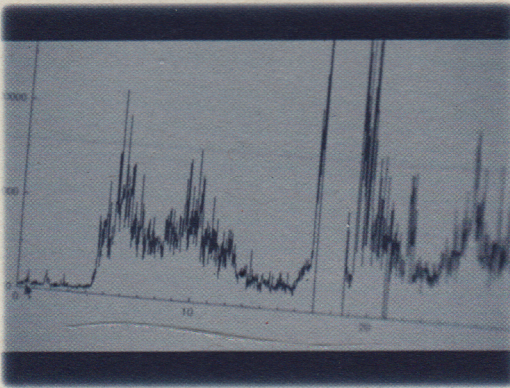
One scientist who believes in this connection is Antony Fraser-Smith, a researcher for the US Navy working at Stanford University, California. The first evidence came when he was studying ultra-low frequency radio waves, which can be used for communication with submarines because such waves penetrate deep into the

oceans and the earth. In October 1989 an antenna at the home of one of his students, just 7 kilometres (4 miles) from the Loma Prieta mountain, gave strange readings that were at first thought to be instrumental errors. Then, 12 days later, the Loma Prieta earthquake struck.

When all the available data were analysed, they revealed something unprecedented in Fraser-Smith's experience. For 12 days before the earthquake electrical activity had been extremely high, and during the three hours before the shock it went off the scale. Fraser-Smith accepts that his views are controversial, but believes that electromagnetic signals may eventually be used to predict earthquakes.

Sceptical seismologists must at least concede that it is theoretically possible for such a signal to be produced. When pressure builds up before an earthquake, it ruptures pockets of water in the earth's crust. This releases energy and could be responsible for the electromagnetic ultra-low-frequency waves recorded by Fraser-Smith.

A graph showing the rise in electrical activity before the Loma Prieta quake



The VAN team

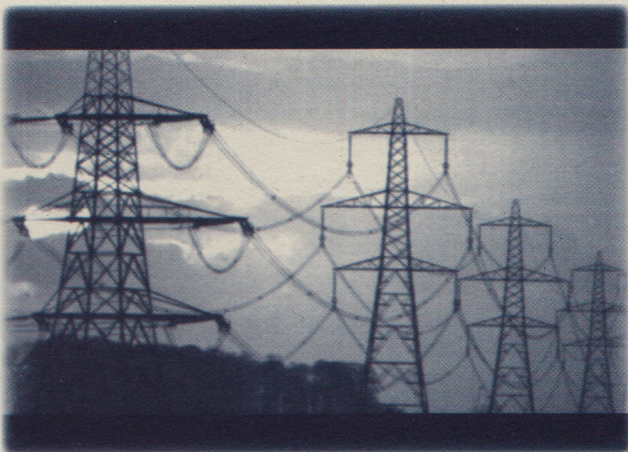
A team led by the Greek scientist Panayiotis Varotsos has also caused controversy with an unorthodox theory involving electrical signals. The VAN group (the acronym is derived from the surnames of Varotsos and two collaborators, Kessar Alexopoulos and Konstantine Nomicos) travels Greece, planting electrodes to detect electrical signals originating below ground. Varotsos claims that before an earthquake, stresses in the rocks generate characteristic weak electric fields. However, these may appear hundreds of kilometres from the epicentre of subsequent tremors, and generally none are recorded close to the epicentre.

In April 1995 VAN notified three foreign research centres that an earthquake would be felt somewhere in two specified areas near its recording station in north-western Greece. The team said the quake would have a magnitude of about 5.0 or 5.5–6.0, depending on which area

it was in. An earthquake actually struck some distance from the named areas, but Varotsos still claimed success, saying that the earthquake had been in an area that had previously shown no seismic activity, so he could not have known that a shock was possible there. He also said that the earthquake's magnitude of 6.6 put it within his claimed range of accuracy – 0.7 each way.

But many scientists are sceptical of such claims of success. Robert J Geller, an American earth scientist working at the University of Tokyo, has particularly criticised the margin of error Varotsos allows when estimating an earthquake's magnitude. He points out that in the case of the 6.6 earthquake, Varotsos could have claimed he predicted any shock between 4.3 and 6.7 on the Richter scale, but that these figures represent shocks that differ in energy by a factor of many thousands.

However, some mainstream earthquake scientists accept that VAN's results are better than they would be if chance alone were operating. And the anger aroused by the group's methods and claims may owe something to its success in winning government financial support.



More electrical connections: the VAN team say that stresses in rocks generate characteristic electric fields before an earthquake



Professor Motoji Ikeya has demonstrated
that plants such as lettuces vibrate in a
high-voltage electric field

Plants and animals

Many people have reported noticing strange behaviour in animals prior to an earthquake. Before the Kobe earthquake, for example, rats and stray cats were said to have disappeared.

Jim Berkland, a geologist who used to work for the US Department of the Interior, now publishes a monthly newsletter about earthquake prediction. One indicator he uses is the number of advertisements for missing pets in the columns of local newspapers. These peak a week or two before earthquakes, he claims, and he conjectures that sensitivity to disturbances in the earth's magnetic field is the reason.

If electromagnetic effects are produced in advance by earthquakes, it may be that living things can detect them. Some organisms are unquestionably sensitive to electromagnetic fields. Certain bacteria and

algae move in the direction of the earth's magnetic field, for instance, and in the laboratory their direction of movement changes if a hand-magnet is placed near them.

Professor Motoji Ikeya of Osaka University has studied the sensitivity to electric and magnetic fields of a variety of animals and plants. He demonstrated that plants such as lettuces and begonias vibrate in the high-voltage field produced by a Van de Graaff generator, and he believes that this explains the reports of leaves on trees shaking just before earthquake shocks. (Professor Ikeya has also shown that the flame of a candle mounted on the charged sphere of a Van de Graaff generator will bend right over. There is a folk belief in Japan that a bent candle flame is a sign of an imminent earthquake.)

In addition, Professor Ikeya has conducted many experiments in which animals responded to electric fields too weak for humans to feel. Catfish thrashed violently; rats began to groom themselves and suffered cramps in their legs; California sea-lions hastily swam away; some young crocodiles bit the electrodes; goldfish were startled. He has even attempted to discover the effects of weak electric fields on a hippopotamus at Kobe-Oji Zoo, but unfortunately the animal was uncooperative.

The idea of irritable crocodiles, startled goldfish and uncooperative hippos might invite scepticism, but there is growing evidence to support Professor Ikeya's conclusions. Joe Kirschvink, of the California Institute of Technology, has concentrated his studies on bees:

'We've discovered that honey bees are extraordinarily sensitive to weak magnetic fields. They're basically able to extract minute signals ... [This research] turned round what was once a romping ground for charlatans: the idea that animals could detect something we

don't was absurd, but it's brought it to a proper neuro-physiological basis. We understand it. We understand the biophysics. We can identify the cells and the wiring for it. We now know that most animals have this sense, even if we don't seem to.'

But perhaps human beings do have such a sense. The bees' ability is based on the presence in their bodies of minute amounts of a highly magnetic iron mineral, magnetite. Intriguingly, magnetite is also present in many tissues of the human body. Could this be an explanation for the claimed abilities of human 'sensitives' who say they can predict earthquakes (see page 23).

This is pure – perhaps even wild – speculation, but mainstream science is nevertheless learning more and more about the ways in which animals can detect subtle changes in the environment. As a result, open-minded accounts of the possibility that animals can sense earthquakes have appeared in the leading science journal *Nature* and on the website of the US Geological Survey's National Earthquake Information Center.

Fish appear to be sensitive to electric fields too weak for humans to detect



Bees are the 'lab rat' for magnetic field sensitivity, according to Joe Kirschvink of the California Institute of Technology



THE SENSITIVES

Ali Rhoden, who believes she can predict the magnitude and location of a coming earthquake from pains in her body



'Sensitives' believe that sensations in their bodies can provide warnings of earthquakes. For instance, Ali Rhoden, who lives near the San Andreas fault, claims that the location and severity of pains and sensations in her body relate to the location and magnitude of a coming earthquake. She told *Equinox*: 'I get headaches in the centre of the forehead for southern California, over my right eyebrow would be the Kuril Islands and Kamchatka, and further out will be the Aleutian Islands. My shoulder is for the South Pacific, Indonesia and the Philippines area.'

However, such claims are not based on evidence that has any credence with mainstream earthquake scientists, and the detail and precision involved – Rhoden claims 'about' 83.4% accuracy – are likely to strike most laypeople as far-fetched. Even if it were proved that characteristic electromagnetic activity precedes earthquakes and that some human beings are sensitive to that activity, it would still seem unlikely that pain over someone's right eyebrow could be specifically related to crust stresses in the Kuril Islands.

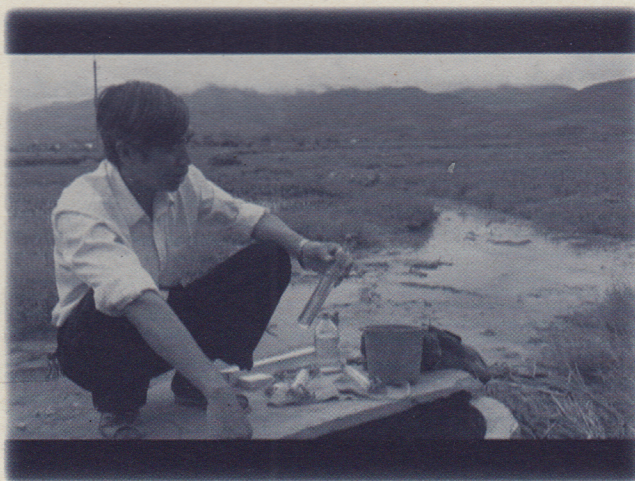
THE CHINESE EXPERIENCE

In the West, folk traditions of earthquake signs are generally viewed with disdain by mainstream scientists. But in China, scientists combine the observation of such signs with readings from modern scientific instrumentation. Over a hundred different kinds of possible precursor are continuously scrutinised. These include water levels in wells and the behaviour of birds (the earth's magnetic field is used by birds in navigation, and birds are often reported to be disturbed before earthquakes) as well as electromagnetic signals, crustal deformations and groundwater chemistry.

'Disaster science' is taken seriously in China: public authorities, in some cases at least, have taken precautions against earthquakes based on its predictions. One scientist working on earthquake prediction, Professor Chen Lide, is revered by thousands of Chinese as the man who saved their lives.

In June 1995 Professor Chen's team found that radon levels in a regularly monitored spring at Menglian, in south-western China, near the border with Burma, had increased suddenly. At the same time a large electromagnetic signal was recorded 300 kilometres (185 miles) to the north. Then there were earthquake tremors just over the border, in Burma.

In July Chen issued an earthquake prediction that by Western standards was amazingly specific. He stated that a major earthquake would strike the Menglian district within three days.



Tests showing raised radon levels in groundwater in Menglian, in south-western China, helped convince Chinese scientists that a major earthquake was about to strike



In 1976 a Chinese disaster scientist correctly predicted an earthquake near the city of Tangshan, in north-eastern China. However, he greatly underestimated the strength of the shock.

The local people belonged to an ethnic minority, regarded by the authorities as likely to disregard government directives, so they were compelled to move out of their homes to earthquake shelters and guarded to prevent their leaving the refuge areas at night. Almost immediately, a major earthquake struck. Only 11 people were killed.

But the Chinese experience of applying disaster science has been mixed. In July 1976 seismographs, crustal strain meters and radon measurements showed that underground stresses in north-eastern China were increasing dramatically. On 14 July, Professor Huang Xiang Ning, an eminent earthquake scientist, warned that an earthquake could be expected in the three-week period from 20 July to 8 August, either west of Beijing or in a triangle centred on the industrial city of Tangshan. But authorities did not take the prediction seriously, except in one small area – Qinglong County, where a newly installed young civil servant, Wang Chuin Qing, acted on it. People were persuaded to move out of their homes, sleeping outside and even setting up their shops in the streets.

In the middle of the night of 27 July, the earthquake struck. Professor Huang and his wife, woken by a deafening rumble, leapt from their bed and ran out of their house. Towards Tangshan they saw a red light in the sky. Huang later said, 'I realised that China had just experienced an earthquake of apocalyptic proportions. This was not a normal earthquake. I felt awful.'



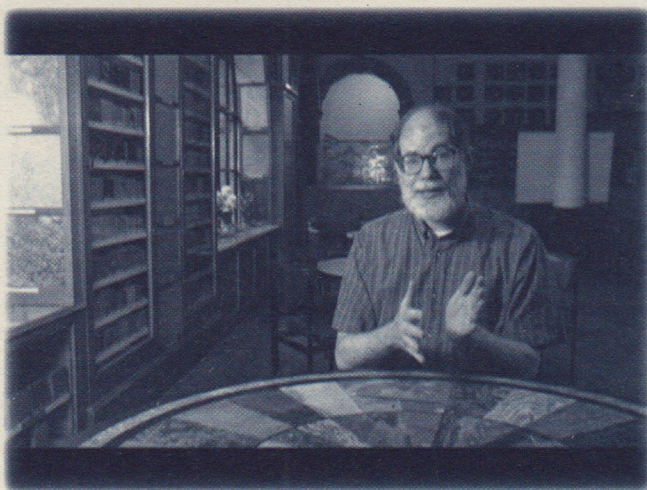
Huang had underestimated the strength of the shock, which was 7.8 on the Richter scale. Furthermore, the earthquake's hypocentre was a mere 12 kilometres below the surface, so that the energy of the shockwaves had decreased little by the time they reached the surface. The earthquake proved to be one of the most devastating of this century, reducing the unprepared city of Tangshan to rubble. Throughout north-eastern China a quarter of a million people died. But in Qinglong County, though more than 180,000 buildings were destroyed, only one life was lost, thanks to Wang Chuin Qing and his colleagues.

Professor Huang feels partly responsible for the loss of human life. But his remorse may be unjustified. Even if he underestimated the damage to come, he issued a warning that was accurate as to time and place.

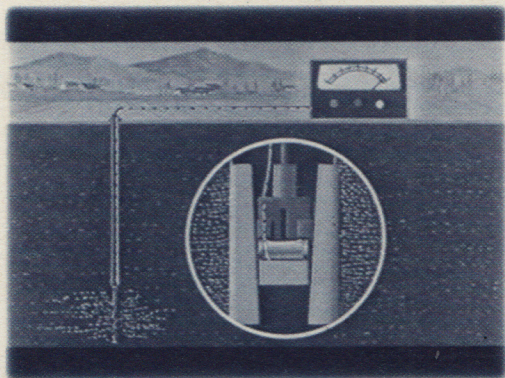
Western sceptics

Nevertheless, many Western scientists believe that apparently successful earthquake predictions in China can be put down to luck. Robert J Geller, an American earth scientist working at the University of Tokyo, told *Equinox*: 'I have not seen lately any articles by the Chinese scientists themselves in refereed scientific journals explaining in detail exactly how it was they allegedly predicted the earthquake, what the evidence was, and so on. So I am very sceptical.' Geller argues that the Chinese faith in earthquake prediction is a relic of the Cultural Revolution, during which disbelief in disaster science became a sign of 'deviationism'.

Robert J Geller of the University of Tokyo, who believes that attempts to predict earthquakes are a waste of time and resources



Strain meters recording slow deformations in the earth's crust may help scientists to predict earthquakes in the future



PROSPECTS FOR PREDICTION

In fact, according to Robert Geller, all attempts to predict earthquakes are simply a waste of time and resources. In 1996 he published a major review of the field. His gloomy conclusion was that 120 years of research had failed to find identifiable precursors of earthquakes. Furthermore, he declared that the failure was probably due less to a lack of adequate networks of instruments than to the sheer complexity of the forces at work. He thinks it likely that any small earthquake can build into a large one, depending on countless immeasurably small details of the surrounding crust. If this model is correct, earthquakes would be effectively unpredictable. Geller told *Equinox*:

'In view of all of those difficulties, the question is not "Why can earthquakes not be predicted?" The obvious question is "Why does anyone seriously think earthquake prediction is worth discussing at the present time?" ... We [Earth scientists] as a community are not getting the technical facts across to the public, and one reason is so much time is wasted discussing completely groundless research on earthquake prediction.'

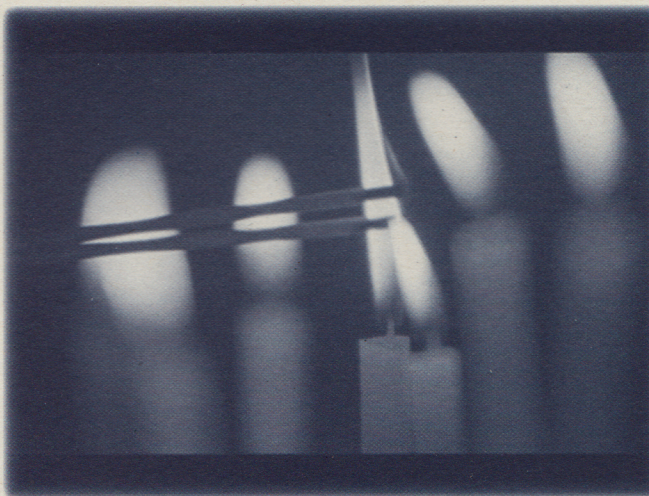
But other mainstream scientists remain optimistic. For example, Paul Silver, of the Carnegie Institution of Washington, advocates the construction of a plate-boundary deformation network of 1,000 to 2,000 sites, spaced 10 kilometres (6 miles) apart around the San Andreas fault. At each site there would be seismographs to record tremors, a borehole 200 metres (660 feet) deep containing a strain meter to record slower deformations of the ground, and a receiver tuned to the Global Positioning System of navigational satellites to record the slowest deformations of all. We would eventually learn, he hopes, how to interpret the data from these sites to provide earthquake warnings.



Other Western scientists favour concentrating effort on some of the indicators of geophysical activity discussed earlier, such as electrical signals or changes in the chemistry of groundwater. Foreshocks – the smaller shocks that often precede a main shock – are another possible area of investigation. Foreshocks occurred in neighbouring Burma before the successfully predicted Menglian earthquake, though none were registered before the disastrous Tangshan earthquake. Some Western observers regard the successes of the Chinese

as being due solely to the attention they pay to foreshocks, with other indicators being irrelevant.

The Earthquake Prediction Subcommittee of the International Association of Seismology and Physics of the Earth's Interior has considered no fewer than 40 different types of possible precursor, but concluded that the vast majority were insignificant. Those they considered to be potentially important included two based on foreshocks and two on chemical changes in groundwater.



Predictions and precautions

Even if earthquake prediction became a respectable technique outside China, difficulties would remain. For one thing, predictions would allow a margin of error. It might be said, for example, that there was a 70% chance of a magnitude 6.0 tremor in a given area within three weeks. Although Chinese officials can instruct the inhabitants of villages to leave their homes during a period of earthquake risk, even they might balk at evacuating a large city for three weeks for the sake of a probability – though

simpler precautions, such as advising residents to stock up with supplies of tinned food, bottled water and torches with fresh batteries, would be possible.

Another problem with prediction is the question of responsibility. If an earthquake failed to occur, might the agency issuing the warning be liable for the disruption it had caused? And might it be liable

for damage arising from earthquakes that it

did not predict? In litigious countries such as the United States, earthquake prediction could be very costly.

An alternative approach is to forget about prediction and to strengthen buildings and highways in earthquake zones. However, the cost of quakeproofing a mile of motorway is greater than the annual cost of the US government's entire earthquake prediction effort, so there are strong economic barriers in that direction. It may be that progress in dealing with earthquakes will take undramatic forms: the gradual replacement of older structures and a slow increase in the accuracy of earthquake predictions to levels that permit advance education if not evacuation.



Quakeproofing structures and roads is one alternative to prediction – but is very costly

PUBLICATIONS

Earth Story by SIMON LAMB and DAVID SINGLETON (BBC Books 1998, £19.99) An illustrated popular account of the planet.

Earthquake Prediction by ANDREW COBURN and ROBIN SPENCE (J. Wiley & Sons 1992, £80.00) Overview of ways to reduce the impact of earthquakes on people, buildings and human settlements. Intended for anyone interested in understanding, organising or participating in earthquake protection.

Earthquakes by BRUCE A BOLT (W H Freeman 1993, £16.95) A standard work by an eminent seismologist.

Earthquakes and Geological Discovery by BRUCE A BOLT (W H Freeman & Co 1993, £23.95) Bolt discusses numerous earthquakes to draw out lessons about their causes and what they teach us about the interior of the earth.

Earthquakes 1980-1994 (British Geological Survey, £5.50) A poster map of the British Isles and the adjoining continental shelf, showing the location and magnitude of earthquakes. Available from the British Geological Survey, Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG Tel: 0115 936 3100.

Earthquakes, Science and Society by DAVID S BRUMBAUGH (Prentice Hall 1998, £19.95) Designed to be used as part of an introductory course on earthquakes, natural hazards and disasters.

Earthshock: Climate, Complexity and Forces of Nature by ANDREW ROBINSON (Thames and Hudson 1993, £14.95) Compelling and informative, with marvellous photos and specially commissioned artwork. Explains latest insights into earthquakes.

How the Earth Works by JOHN FARNDON (Dorling Kindersley 1992, £14.99) An illustrated look at our world and how it works for younger readers, with practical experiments that can be done at home.

Volcanoes: a Planetary Perspective by PETER FRANCIS (Oxford University Press 1993, £25.00) Sets out to explain volcanic processes using accounts of major eruptions.

Why the Earth Quakes by MATTHYS LEVY, MARIO SALVADORI and MICHAEL LILLY (W W Norton & Company, £9.95) An account of the history of the understanding of earthquakes, exploring the nature of earthquakes and volcanoes and the prediction of their behaviour, and providing an up-to-date description of possible protection measures.

WEBSITES

GLOBAL SEISMOLOGY AND GEOMAGNETISM GROUP
OF THE BRITISH GEOLOGICAL SURVEY

www.gsg.nmh.ac.uk/gsg.html

Includes UK earthquakes of the last 30 days, a listing of larger UK earthquakes in the 20th century, earthquake questions and answers and a glossary.

NEW SCIENTIST EARTHQUAKE PAGE

**[www.newscientist.co.uk/nsplus/insight/
quakes/quakes.html](http://www.newscientist.co.uk/nsplus/insight/quakes/quakes.html)**

Includes links to *New Scientist* articles and news reports and to other websites.

SYZYG

www.szygyjob.com

A monthly earthquake prediction newsletter published by Jim Berkland, a Californian geologist who claims to be able to predict earthquakes accurately.

US GEOLOGICAL SURVEY'S

NATIONAL EARTHQUAKE INFORMATION CENTER

www.neic.cr.usgs.gov

Includes general earthquake information, a searchable database and links.

US GEOLOGICAL SURVEY

quake.wr.usgs.gov

Maps and lists of recent US earthquakes; why and how to prepare; earthquake FAQs and information; links.

In addition, the EARTH GALLERIES of the NATURAL HISTORY MUSEUM (Cromwell Road, London SW7 5BD; tel: 0171 938 9123) have some excellent displays on earthquakes.



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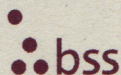
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EARTHQUAKES CAN be hugely destructive, and they strike without warning. Or do they? Earthquake 'sensitives' believe sensations in their bodies presage shocks, many people in earthquake zones believe warnings can be seen in such things as the weather and animal behaviour, and some scientists are convinced that predictions can be made by measuring electric fields or changes in groundwater chemistry.

This booklet, published to accompany the Channel 4 *Equinox* programme *A Sense of Disaster*, looks at the science of earthquakes and at attempts to predict them, scientific and otherwise.

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